New Core and Spectrum Balancing Algorithms for Space Division Multiplexed Elastic Optical Networks

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***Abstract*—This paper proposes two new algorithms for core and spectrum allocation in Elastic Optical Networks with Space Division Multiplexing. In order to avoid the effect of inter-core crosstalk, a Core Balancing Algorithm (CBA) is proposed for core allocation, and a Spectrum Balancing Algorithm (SBA) for spectral allocation. Such algorithms prove to be efficient in terms of circuit blocking probability and blocked data ratio. They achieve at least 55.7% gain in terms of circuit blocking probability and 41.1% gain in terms of blocked data ratio when compared to other evaluated algorithms. It is shown that the proposed algorithms achieve low computational cost and higher energy efficiency than other similar algorithms.**

I. Introduction

New applications, such as cloud computing solutions, telemedicine, and ultra-definition (4K) video streams, demand high capacity from the communication infrastructure. To meet these and other demands, the optical network capacity must be improved to support this growing traffic. Towards this end, Elastic Optical Networks (EONs) [1] appear as a solution to compose the Internet infrastructure. In an EON, the optical spectrum is split into narrow band channels called frequency slots. This type of division offers greater efficiency in the allocation of spectral resources when compared to fixed grid models [2]. Recently, in order to increase the optical fiber capacity, Space Division Multiplexing (SDM) has been considered [3]. With SDM using singlemode transmission in each core of a multi-core fiber (MCF), multiple distinct cores are used to send the information data. Thus, SDM-EONs can handle much higher volumes of traffic.

To allocate an optical circuit in an SDM-EON, the issue of Routing, Spectrum, and Core Assignment (RSCA) [4] should be considered. The RSCA problem consists of: *i)* defining the route that the circuit will take from the source node to the destination node; *ii)* select which core will be used for data transport; and *iii)* which slots will be allocated to the circuit. During transmission, the optical signal is affected by interference that can impair communication between the transmitter and the receiver. Considering interference like the inter-core crosstalk (XT) resulting from transmission along the MCF makes the model more realistic. The XT occurs when the same frequency slot is used in nearby cores. The RSCA problem can be divided into two subproblems: the routing subproblem and Spectrum and Core Assignment (SCA) subproblem [4].

The aim of this paper is the proposal of solutions for the SCA subproblem. A novel set of metrics to assess the spectrum state is proposed, aiming to avoid the XT effect. Based on these metrics, two new algorithms are proposed in this paper: Core Balancing Algorithm (CBA) and Spectrum Balancing Algorithm (SBA). The proposals enable reduction of blocking probability and increase energy efficiency of the network.

This paper is organized as follows. Section II presents related works on SDM-EONs. Section III presents general approaches on SDM-EON. Section IV describes the CBA and SBA algorithms. In Section V, the performance results of the proposed algorithms are presented and compared with the ones of other algorithms. Conclusions are presented in Section VI.

II. Related Works

The RSCA problem in SDM-EONs has been addressed considering issues such as XT and other physical layer problems. Two kinds of algorithms have been proposed to tackle the XT impact on the SDM-EON performance when solving the SCA problem: i) XT-aware algorithms which use the XT levels, occurring in the SDM-EON when the request appears, to make a decision on the core and spectrum assignment [3], [4], [5]; and ii) XT-avoid algorithms, where the SCA tries to avoid overlapping slots in adjacent cores, without computing the XT level [6], [7], [8]. Despite their efficiency, XT-aware algorithms have greater computational complexity compared to XT-avoid algorithms. Seeking to solve the SCA problem efficiently and with less computational complexity, the proposal of this paper belongs to the XT-avoid class.

A dynamic method of classifying cores based on the bandwidth required for multi-core networks was proposed in [7]. The exposed method, which belongs to XT-avoid class, seeks to prioritize certain cores to reduce XT. In addition, authors proposed a method to reduce network fragmentation.

An evaluation of the benefits of SDM solutions in terms of maximizing the capacity and spatial efficiency of data center networks was proposed in [9]. The authors proposed a bi-directional core priority mapping strategy and a spectrum allocation scheme in order to allocate network resources.

A new concept for measuring XT, called Inter-Core Spectrum Crosstalk Measurement (IC-SCM), based on spectrum status was presented, and a dynamic routing, core, and spectrum assignment with minimized XT by evaluating and incorporating the IC-SCM was proposed in [10].

A method of allocating spectrum for the RSA problem in networks with MCFs was proposed in [8]. The proposal belongs to the XT-avoid class and it selects frequency slots dynamically in adjacent cores in order to minimize crosstalk.

In this work, XT-avoid algorithms are proposed to improve the efficiency on optical resources allocation when compared with other XT-avoid algorithms mentioned in this section. To achieve this, a novel set of metrics to evaluate the spectrum state is proposed and applied, aiming to avoid the XT. These metrics can define, from a set of free resources, a candidate circuit with a lesser probability of spectral overlapping in the neighborhood, by considering the number of circuits already active in the spectral neighborhood and assigning weights to identify less effective solutions. Thus, a candidate circuit with many active circuits in neighboring cores is considered a less efficient solution (high weight) and is not selected by the algorithm. Moreover, the proposed algorithms prioritize the allocation of new circuits in different spectral regions between adjacents cores. Consequently, the proposed algorithms choose each new circuit with a lower incidence of XT, improving its quality of transmission (QoT). The proposed metrics and the algorithms for spectrum and core assignment are the main original contributions of this paper.

III. Methods and Metrics of Performance Assessment

In a SDM-EON, the spectrum available in each core of the MCF is split into frequency slots. Each request for allocation of a new optical circuit contains the source, destination, and information bit rate. From this data, the SCA algorithm selects a core and a set of frequency slots to supply this demand. The number of slots varies according to the requested capacity and the modulation format used. When available resources exist in the network, a dedicated optical circuit will be allocated to the request; otherwise, the request is denied (known as request blocking). For the allocation of spectral resources, it is necessary to define which set of slots the optical circuit will use. This definition must consider two constraints [2]: *i)* spectral contiguity, which requires that all slots of a circuit must be adjacent to each other in each route link; and *ii)* spectral continuity requires the use of the same set of slots in all links of the selected route. Different algorithms can be used for spectral allocation, such as the first fit, last fit, best fit, and random fit [2], [11].

Due to several physical layer impairments, the QoT of the circuit degrades while the information signal propagates along the EON. Optical amplification is usually performed by erbium doped fiber amplifiers (EDFAs), which add amplified spontaneous emission (ASE) noise to the information signal [12]. Nonlinear interference (NLI) manifests due to propagation along the optical fiber making an optical circuit to cause interference in itself, self-phase modulation (SPM), and interference in other circuits, cross-phase modulation (XPM), and four-wave mixing (FWM). One way to measure QoT levels is through the optical signal to noise ratio (OSNR). In SDM-EONs transmitting raised cosine spectrum signals with quasi-minimum bandwidth, the OSNR is given approximately the ratio between the power spectral density (PSD) of the circuit and the PSD of the ASE noise and NLI that affects it. The OSNR is used as a QoT criterion in this work. The model presented in [12], [13] is used to calculate the OSNR considering the ASE noise and NLI effects.

Another important impairment of an SDM-EON is the XT, which occurs when the same frequency slot is used in nearby cores. The shorter the distance between the cores, the greater the XT effect. In order to quantify the XT level in an optical circuit that considers the partial overlap between spectrum of optical circuits in different cores, a model has been presented [4]. Following this model, the total normalized mean XT power (XT level) of the circuit i is given by [4]

$$XT_{\mu,i}^{(tot)} = \sum_{l=1}^{N_i} XT_{\mu,i}^{(l)}, \tag{1}$$

where N_i is the number of links of the circuit i and $XT_{\mu,i}^{(l)}$ is the normalized mean XT power of link l, given by

$$XT_{\mu,i}^{(l)} = \frac{P_{XT,i}^{(l)}}{P_{S,i}}, \tag{2}$$

with $P_{XT,i}^{(l)}$ the mean detected XT power of circuit i generated in link l, and $P_{S,i}$ the signal power of circuit i. The mean detected XT power $P_{XT,i}^{(l)}$ is given by

$$P_{XT,i}^{(l)} = \sum_{j=1}^{N_a} (I_{SO,i,j} \cdot P_{S,j} \cdot h_l \cdot L^{(l)}), \tag{3}$$

where N_a is the number of cores adjacent to the core used by circuit i, $P_{S,j}$ is the signal power of the interfering circuit that uses core j, h_l is the power-coupling coefficient of link l, $L^{(l)}$ is the length of link l and $I_{SO,i,j}$ is the slot overlap index between circuits i and j given by $I_{SO,i,j} = N_{SO,i,j}/N_{S,j}$, with $N_{S,j}$ the amount of slots of circuit j, and $N_{SO,i,j}$ the number of overlapping slots between circuits i and j (which means how many of the slots of circuit i have the same index as in circuit j, excluding the guard band).

When the request for the establishment of a new circuit arrives, the RSCA algorithm calculates a route between the source node (o) and the destination node (d). The core and set of slots to be used are also calculated. If there are no free resources, the request will be blocked. If resources are available, then the control plane, based on the physical layer model, analyzes the OSNR value and the XT level for the candidate circuit. In this paper, all QoT values (OSNR and XT) are obtained dynamically during simulation by the control plane simulator. If the candidate circuit's OSNR is not adequate, a block will occur due to insufficient QoT in the new circuit (QoTN). Otherwise, the impact of the possible allocation of this circuit on the previously established circuits will be analyzed. If the impact affects any of the circuits previously activated so that the OSNR of it does not comply with the OSNR threshold, the new circuit will be blocked due to the insufficient QoT for the other circuits (QoTO). If OSNR and XT values are acceptable, the circuit will be established. The OSNR and XT levels are considered acceptable if they are within the corresponding values QoT thresholds. The values of these thresholds, which have been defined in other works, are presented in Section V.

Two metrics, circuit blocking probability (CBP) and blocked data ratio (BDR), are used to categorize the performance of the algorithms from numerical simulation results. CBP is the ratio of the number of blocked circuits to the total number of requested circuits, whereas BDR considers also the capacity and lifetime of these circuits. The BDR measures the fraction of blocked data (quantity of information bits of blocked circuits relative to the number of bits of all requested circuits) and is given by $BDR = (\sum_{i\ (\text{blocked circuits})} B_i \cdot T_i)/(\sum_{i\ (\text{all requested circuits})} B_i \cdot T_i)$, where B_i is the bit rate of the i-th requested circuit and T_i is the time that the i-th requested circuit would be active.

In addition to CBP and BDR, algorithms are evaluated according to their energy efficiency. Energy efficiency is a metric that measures the number of bits transmitted per Joule of energy consumed. For this, the total amount of bits transmitted is divided by the total network energy consumption. The total network energy consumption is obtained by adding the energy consumed by transponders, switches, and EDFAs [14], [15].

IV. Proposed Algorithms

In this section, the two new algorithms proposed to choose the core and spectrum in a balanced way, aiming to avoid the XT effect, are presented. Section IV-A introduces the SBA, whereas the CBA is discussed in Section IV-B.

A. Spectrum Balancing Algorithm

As XT affects slots with same index in neighboring cores, the SBA prioritizes slots with different frequency between adjacent cores. Figure 1 presents the algorithm general idea.

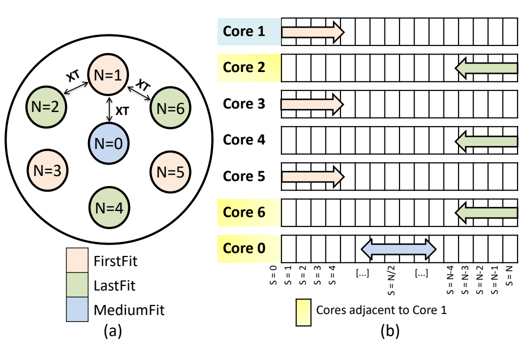

Fig. 1. Spectrum Balancing Algorithm (SBA).

In Figure 1 (a), we demonstrate what the core arrangement is like in a seven-core MCF. In general, the SBA seeks to occupy the slots of neighboring cores in opposite directions. Taking Figure 1 (b) as an example, the SBA occupies core 1 using the lowest index available slots (first fit algorithm). On the other hand, the slots of cores 2 and 6 (neighbors of core 1) are allocated from the highest to the lowest index (last fit). It is worth mentioning that core 0 (see Figure 1) is a neighbor of all other cores. Therefore, for core 0, the SBA allocates the slots starting from the center of the spectrum to the ends. This differentiated slot allocation in core 0 aims to decrease the XT level induced by the center core in all other cores, and vice-versa. Thus, the SBA strategy avoids slot allocation of the same index in neighboring cores.

Algorithm 1 : SBA

Input Route r, number of slots required s, Core c

1: Compute the set F of feasible spectrum bands f
2: **if** $F \neq null$ **then**
3:   **if** c is the central core **then**
4:     $spectrum \leftarrow$ Set of $slots \in F$ closest to the middle of the spectrum
5:   **else if** $c \in N = (1, 3, 5)$ **then**
6:     $spectrum \leftarrow$ Set of $slots \in F$ closest to the beginning of the spectrum
7:   **else if** $c \in N = (2, 4, 6)$ **then**
8:     $spectrum \leftarrow$ Set of $slots \in F$ closest to the end of the spectrum
9:   **end if**
10:   **return** $spectrum$
11: **end if**
12: **return** request is blocked

Algorithm 1 presents the SBA pseudocode. First, for a given route r and requested number of slots s, the SBA calculates a feasible set of candidate spectrum F, where each candidate spectrum is free, continuous and contiguous (line 1). Then, if the input core c is 1, 3, or 5 the SBA seeks the spectrum slice of F closest to the spectrum beginning (first fit). For the cores 2, 4, or 6 the SBA prioritize the slots at the end of the spectrum (last fit). For core 0 (central core), which influences the crosstalk of all others, the SBA prioritizes the set of slots farthest from the beginning and end of the spectrum concurrently. Thus, the spectral allocation is made to minimize slot overlapping and, consequently, the crosstalk in the network. The SBA time complexity is calculated as $O(|E| \cdot |S|)$, where $|E|$ is the number of links in route, and $|S|$ is the number of slots in each link.

B. Core Balancing Algorithm

Due to the impact of XT on the EON-SDM network performance, we propose the CBA to avoid XT. The CBA assesses the spectral state of each core considering the utilization of the neighboring cores and its own use. The key idea of the CBA is to choose a core that has neighboring cores with low spectral occupancy. In general, when the utilization of the neighboring cores of a particular core increases, the probability of overlapping between the slots of that core and the slots of its neighbors also increases. The criterion for selecting a core relies on three proposed metrics described in the following.

1) Total Use in Neighbors (TUN): it calculates the total number of frequency slots used in the adjacent cores. The TUN of a core c is given by:

$$TUN_c = \sum_{l=1}^{N_l} \sum_{j=1}^{J_{tot}} q_{l,j}, \tag{4}$$

where N_l is the number of links of the route, J_{tot} is the number of cores adjacent to core c (neighboring cores), and $q_{l,j}$ is the number of slots in use in link l and core j.

2) Weighted Use of Neighbors (WUN): in contrast to TUN, WUN verifies the use of the neighborhood in a more specific way, based on the balancing of SBA groups. It splits the optical spectrum into three regions, beginning (first third), middle (second third), and end (last third). Each region has an associated weight α_i ($1 \leq i \leq 3$). The value of α_i depends on the mode of spectral allocation in each core, presented in the SBA algorithm. The WUN value is given by:

$$WUN_c = \sum_{l=1}^{N_l} \sum_{j=1}^{J_{tot}} q_{1,l,j} \cdot \alpha_1 + q_{2,l,j} \cdot \alpha_2 + q_{3,l,j} \cdot \alpha_3 \tag{5}$$

where $q_{n,l,j}$ is the number of slots in use in the region n, link l and core j.

3) Use in the candidate core (UC): it calculates the number of all occupied slots in core under test. This metric prevents the same core from being chosen successively, providing a balance in core choice.

These three metrics measure the utilization of the core under test and its neighbors. TUN, WUN, and UC have equal influence for CBA. Therefore, CBA considers the sum of the values obtained by each of the three metrics as decision criterion, and chooses the core with lower sum.

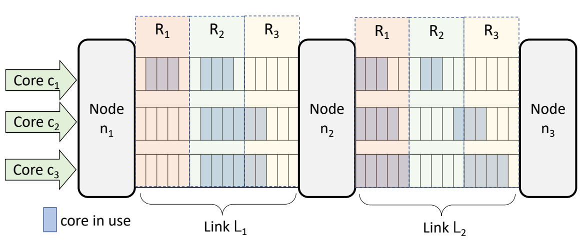

Fig. 2. Core Balancing Algorithm (CBA).

Figure 2 illustrates the use of these metrics. When the CBA evaluates core c_2, metrics TUN, WUN, and UC are calculated. To calculate the TUN value, the algorithm counts all the slots in use in the cores adjacent to core c (for Figure 2, the TUN of c_2 is 26). To calculate the WUN value, the algorithm counts how many slots are in use in each of three regions (R_1, R_2, and R_3). Then, the algorithm associates the number of slots in each region with the appropriate weight (α_1, α_2, or α_3). The weight is defined, in each case, according to the allocation method of the SBA strategy (Section IV-A), where higher weights are associated with the region prioritized by the analyzed core (where $\alpha_i \in \{1, 2, 3\}$). Weighted assignments make WUN give more or less importance to a given region, considering its priority (for Figure 2, the WUN of c_2 is 57, considering α_1=3, α_2=2, and α_3=1). Finally, the UC metric is calculated from the number of slots used by the evaluated cores (for Figure 2, the UC of c_2 is 13). The CBA pseudocode is presented in Algorithm 2.

Algorithm 2 : CBA

Input Route r
for each Core $c \in$ set of Cores **do**
  Calculate TUN for c
  Calculate WUN for c
  Calculate UC for c
  $weightOfC \leftarrow TUN_c + WUN_c + UC_c$
end for
$chosenCore \leftarrow$ core with lower $weightOfC$ value
return $chosenCore$

The CBA time complexity is calculated as $O(|E| \cdot |S| \cdot |C|)$, where $|E|$ is the number of links in route r, $|S|$ is the number of slots in each link, and $|C|$ is the number of cores in link.

V. Performance Results and Discussion

The SLICE Network Simulator (SNetS) [11] was used to assess the performance of the proposed algorithms. In each run, 100,000 circuit requests were generated. Request generation is a Poisson process with an average rate of λ and the average circuit retention time is distributed exponentially with an average of $1/\mu$. Traffic load is evenly distributed among all pairs of source and destination nodes. Requests with information bit rates of 100, 150, 200, 250, 300, 350, and 400 Gbps are generated, following the ratio of 7, 6, 5, 4, 3, 2, and 1, respectively. The traffic load, in Erlangs, is $\rho = \lambda/\mu$. For each evaluation scenario, 10 runs were performed with different seeds for generating random variables. In all of the results presented, a confidence level of 95% was considered.

The study considers that each MCF has seven cores, as in [5], [6], with the available spectrum of each core divided into 320 frequency slots. Each slot has a bandwidth of 12.5 GHz. The guard band has the bandwidth of a slot. Other parameters used in the study are listed in Table I.

TABLE I
Values of physical parameters [4], [16], [17].

Definition	Value
Fiber dispersion parameter (D)	16 ps/nm/km
Fiber nonlinearity coefficient (γ)	1.3 $(\text{W} \cdot \text{km})^{-1}$
Span length (L_s)	80 km
Amplifier noise figure (NF)	5 dB
Forward error correction (FEC)	12 %
Power-coupling coefficient (h_l)	6.4×10^{-9} m^{-1} or 1.5×10^{-9} m^{-1}

The study considers also polarization division multiplexed signals and five modulation formats: BPSK, QPSK, 8-QAM, 16-QAM, and 32-QAM. The modulation format is chosen according to its maximum reach, prioritizing the modulation format with more bits per symbol. The maximum reach of each modulation format, as well as their respective OSNR and XT thresholds are shown in Table II. The bandwidth of the i request with a given information bit rate R_i, for a modulation level M (number of distinct symbols of the modulation format), and forward error correction (FEC) overhead F, is given by $B_i = (1.1R_i\,(1+F))/(2\log_2 M)$ [18]. Then, an integer number of frequency slots must be assigned to cover the signal spectrum.

TABLE II
CHARACTERISTICS OF MODULATION FORMATS [5], [19], [20].

	BPSK	QPSK	8QAM	16QAM	32QAM
Reach (km)	10,000	5,000	2,500	1,250	650
OSNR thres.	5.5 dB	8.5 dB	12.5 dB	15.1 dB	18.1 dB
XT threshold	-14 dB	-18.5 dB	-21 dB	-25 dB	-27 dB

The topologies evaluated in the study were the NSFNet and the EON [6], [11]. The performance of the topologies are evaluated in two scenarios: i) high XT level, with power-coupling coefficient (h_l) equal to 6.4×10^{-9} m^{-1} [4]; and ii) low XT level, with power-coupling coefficient (h_l) equal to 1.5×10^{-9} m^{-1} [4]. The proposal CBA+SBA is compared with three other strategies: i) An incremental cyclic core choice strategy ($e.g.$: choose core 1; choose core 2; choose core 3; [...]; choose core 1; [...]) associated with the proposed SBA, named IC-SBA. ii) A random core strategy with spectral first fit allocation, named RC-FF; iii) Choice of core through the Core Prioritization Algorithm [7] with random fit spectral allocation, named CP-RF. The Dijkstra algorithm is used to choose the route in all algorithms.

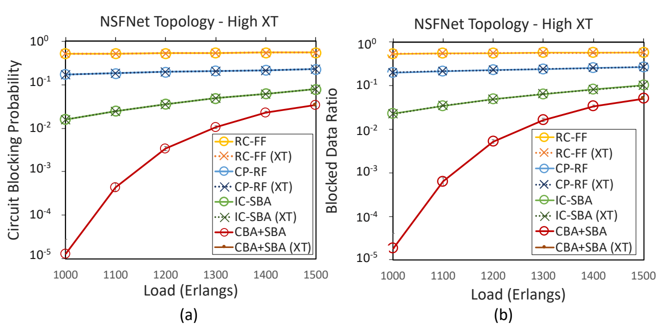

Fig. 3. Results for the NSFNet topology with high XT level. (a) Circuit blocking probability. (b) Blocked Data Ratio.

Figure 3 shows the results for the NSFNet topology with high XT level, in terms of CBP and BDR. For the scenario with high XT level, CBA+SBA obtained lower CBP and BDR. The CBA+SBA gain relative to IC+SBA (second best performance) was 55.7% in the CBP (1500 Erlangs) and 50.3% in the BDR. For the RC-FF, CP-RF, and IC-SBA algorithms, it is noted that the blocking was predominantly caused by the XT, with little occurrence of other blocking types (e.g: QoTN and QoTO). This fact is observed by the overlap between the total blocking (continuous lines) and the blocking by XT (dashed lines, X marking) in each algorithm.

Figure 4 shows results for the NSFNet topology with low XT level. In this scenario, the CBA-SBA performance is worse

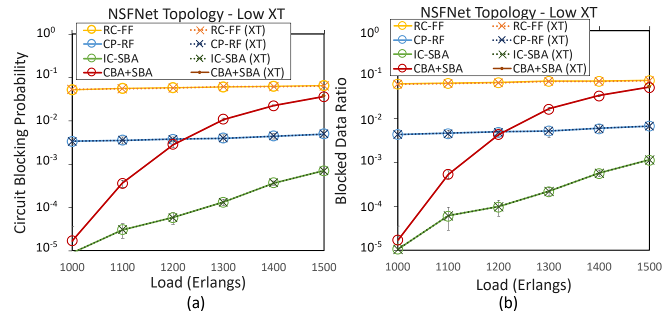

Fig. 4. Results for the NSFNet topology with low XT level. (a) Circuit blocking probability. (b) Blocked data ratio.

than the IC-SBA one. This is due to the CBA core allocation method, which is blocked due to lack of resources as it avoids using a core with a probable incidence of XT, even if it has free resources. Thus, for scenarios with low XT incidence, the use of SBA proposal with a simple incremental core allocation strategy (IC-SBA) obtained the best results. In the low XT scenario, the IC-SBA proposal obtained a gain of 85.7% in terms of CBP at the highest load point relative to CP-RF (second best performance). In terms of BDR, the IC-SBA algorithm obtained a gain of 83.0% relative to CP-RF.

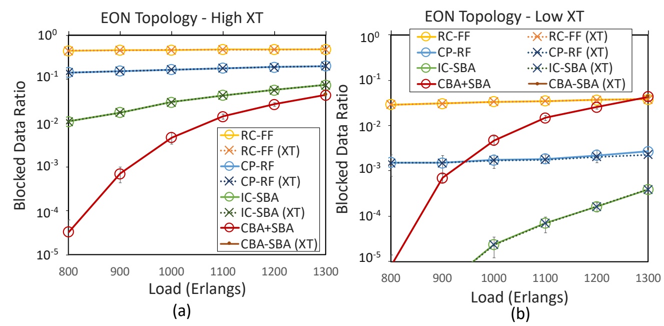

Fig. 5. BDR results for the EON topology. (a) BDR with high XT level. (b) BDR with low XT level.

Figure 5 shows BDR results for the EON topology. As for the EON topology, the CBP results are similar to the NSFNet topology, Figure 5 shows only the BDR results. In the high XT scenario, CBA-SBA obtained the lower BDR in the EON topology. CBA-RSA achieved a 41.1% gain over IC-SBA at the highest load point. The gain of CBA+SBA was at least 78.3% relative to CP-RF. The impact of XT was predominant in BDR of the RC-FF, CP-RF and IC-SBA algorithms. In the scenario of low incidence of XT, the IC-SBA also achieved the best results. The IC-SBA gain over CP-RF was at least 85.5%, and 98.0% over RC-FF. According to the blocking probability results, the SBA performs well in all scenarios, while CBA is recommended for scenarios with a high XT incidence.

Figure 6 shows that, in the high XT incidence scenario, the proposed algorithms (IC-SBA and CBA+SBA) obtained the highest energy efficiency among the algorithms evaluated. For the highest load point in the NSFNet topology, the CBA+SBA algorithm was 4.7% more energy efficient than the IC-SBA

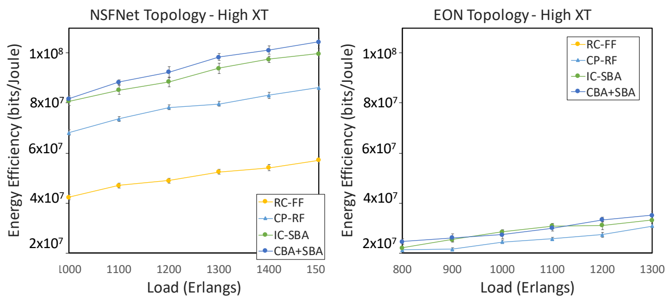

Fig. 6. Energy efficiency of different algorithms for (a) NSFNet topology with high XT level, and (b) EON topology with high XT level.

one, 21.3% more efficient than the CP-RF one, and 82.7% more efficient than the RC-FF one. For the EON topology, CBA+SBA and IC-SBA obtained equivalent results for some load points. For the highest EON topology load point, the CBA+SBA algorithm was 5.6% more energy efficient than the IC-SBA one, 13.9% more efficient than the CP-RF one, and 79.5% more efficient than the RC-FF one. This behavior occurs because, in the high XT level scenario, the algorithms more sensitive to XT have more blocking, which decreases the amount of bits transported and, consequently, their energy efficiencies. Therefore, the results show that the proposals achieve better energy efficiency in high XT level scenarios.

VI. Conclusion

This paper proposed two new algorithms for resource allocation in SDM-EONs. Core Balancing Algorithm (CBA) was proposed for core allocation, and Spectrum Balancing Algorithm (SBA) was proposed for spectral allocation. These algorithms are XT-avoid; hence, they present less computational complexity than other algorithms (such as XT-aware). It was found that both algorithms improve performance, with at least 55.7% gain in terms of CBP, 41.1% gain in terms of BDR, and up 13.9% of energy efficiency.

Generally, XT affects seriously the performance of resource allocation algorithms in SDM-EONs in scenarios with high XT level. The proposed algorithms have been proved to be effective in avoiding the XT impact. CBA proved to be efficient in scenarios with high XT incidence, reducing the blocking probability in these scenarios. Thus, the use of CBA is indicated for SDM-EONs highly affected by XT, which need to mitigate the XT effect. SBA, on the other hand, proved to be efficient both in the high and low XT level scenario.

Despite this paper uses a seven-core MCF, the key idea of the proposed algorithms can be generalized for other core counts. For this, the division of spectrum groups should be adapted, with different priority regions for CBA and SBA. An analysis with different core count is in progress.

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